



**Allen Face**  
europe

## **AN INTRODUCTION TO FF, FL, AND FMIN**

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by **Allen Face**

*Honorary Member of the American Concrete Institute &  
Author of the Fmin and FF/FL Floor Profile Numbering Systems*

# 1

## WHAT ARE F-NUMBERS?

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The F-Number System (ASTM E-1155) is a rational, comprehensive, and extraordinarily effective methodology for specifying and controlling both floor flatness and levelness in all situations where the traffic patterns are unconstrained. F-Numbers replace all forms of the traditional “gap under the straightedge” type tolerance, since every such format - regardless of wording – is known to be incompetent per force. For reasons that quickly become obvious upon use, F-Numbers are also much superior to both the TR-34 Property II and Property IV Free Movement and the DIN 18202 5.4 Table 3 specification formats. As explained below, both those systems suffer from serious practical problems owing to their inflexibility, unreality, and failure to address equitable remedy.

The rules for collecting the F-Number data, making the F-Number calculations, and reporting the F-Number results are all set forth in ASTM E 1155M: Standard Test Method for Determining FF Floor Flatness and FL Floor Levelness Numbers (Metric).

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## WHAT ARE FMIN NUMBERS?

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For controlling profile quality, every floor falls into one of two use categories: **defined** traffic or **random** traffic. All floors supporting the operation of any type of fixed-path vehicle system (e.g. a wire or rail guided narrow aisle lift truck) are deemed **Defined Traffic** floors. All floors that are not categorized as Defined Traffic are automatically deemed to be **Random Traffic** floors. Since ASTM E 1155M strictly limits the use of FF and FL numbers to Random Traffic floors:

5.3 Results of this test method shall not be used to enforce contract flatness and levelness tolerances on those floor installations primarily intended to support the operation of fixed-path vehicles systems (for example, narrow aisle warehouse floors), an alternative method must be used to control the profiles of Defined Traffic floors. Since 1979, on the great majority of VNA warehouse construction projects around the world, that alternative method has been the Fmin System.

The Fmin System is proprietary and controlled entirely by Allen Face. Its details are set forth on the Allen Face Europe website ([www.allenface-europe.com](http://www.allenface-europe.com)). Again, for reasons that quickly become obvi-

ous upon use, the Fmin System is much superior to both the TR-34 Property I, II, and III Defined Movement and DIN 15185 specification formats. As explained below, like their “free movement” counterparts, both these systems also suffer from serious practical problems owing to their inflexibility and failure to address the essential question of equitable remedy.

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## WHAT ARE FF AND FL?

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ASTM E1155M describes the measurement and calculation of two kinds of F-Numbers: **FF** numbers and **FL** numbers. **FF** (Flatness) numbers control the floor’s local bumpiness. **FL** (Levelness) numbers control the floor’s local inclination relative to horizontal. The higher the floor’s FF and FL numbers, the better its flatness and levelness. When paired together, the FF number always precedes the FL number (viz. FF/FL).

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## HOW DO A FLOOR’S FF AND FL NUMBERS RELATE TO ITS FMIN NUMBER?

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**They don’t**, and that is why the two systems are **never** interchangeable. The FF and FL system employs a statistical sampling procedure that results only in an estimation of the subject floor area’s actual FF and FL numbers. In contrast, since the Fmin system is “wheel track specific”, it has no need for statistics. It simply measures 100% of each defined wheel track and then applies six different pass/fail criteria simultaneously to determine the acceptability of each cm thereof. Nonetheless, much experience has shown that the following equations do provide a rough equivalence between the two systems:

$$\mathbf{Fmin = 0.71 OAFF = 1.18 OAFL = 1.18 MLFF = 1.96 MLFL}$$

(where OAFF, OAFL, MLFF, and MLFL are the special FF and FL numbers described below).

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## HOW ARE THE FF, FL, AND FMIN NUMBERS SCALED?

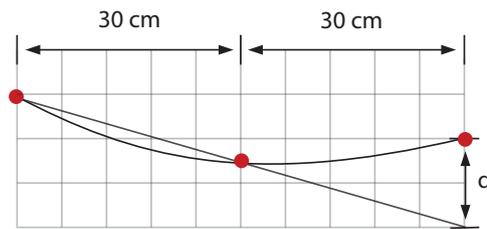
The FF, FL, and Fmin number scales are all linear. This means that:

- an FF-30 floor is exactly twice as flat as an FF-15 floor,
- an FL-20 floor is exactly half as level as an FL-40 floor, and
- Fmin-100 wheel tracks are exactly twice as flat and level as Fmin-50 wheel tracks.

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## WHAT EXACTLY IS FF MEASURING?

The profile variable controlled by FF is the **incremental curvature over 600mm**. It is the dimension  $q$  shown in the following diagram.

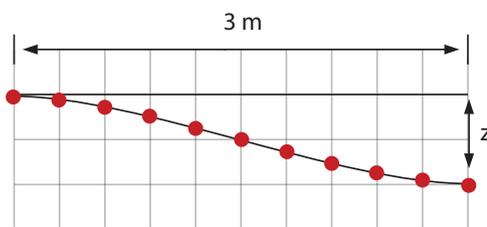


Because the floor is curving upward,  $q^1$  in the diagram is positive. If the floor were curving downward, then  $q$  would be negative.

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## WHAT EXACTLY IS FL MEASURING?

The profile variable controlled by FL is the **incremental slope over 3m**. It is the dimension  $z$  shown in the following diagram.



Because the floor is sloping downward from left to right,  $z$  in the diagram is negative. If the floor were sloping upward from left to right, then  $z$  would be positive.

## 8

### WHAT ARE OVERALL FF AND FL NUMBERS?

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A project's specified overall FF and FL numbers (abbreviated as **OAFF** and **O AFL**) are the FF and FL numbers to be exhibited by the entire project floor when completed. Since these two values define the **average floor flatness and levelness quality** to be delivered by the installer over the entire project, they can never represent the profile quality to be exhibited by any smaller area. Consequently, neither the OAFF nor the O AFL can ever refer to the profile quality required in any single panel, bay, or placement (unless that single panel, bay, or placement alone constitutes the entire project floor).

Every properly drawn F-Number specification must require the installer to deliver a specific set of overall FF and FL numbers (see below for limitations on the specification of O AFL).

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### WHEN ARE THE OVERALL O AFF AND O AFL NUMBERS MEASURED?

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To ensure that the test only gauges the quality of the installer's work and is not tainted by any subsequent natural movements of the floor (e.g. curling or deflection), ACI 117-10 requires the completion of all F-Number testing within 72 hours following installation. If an elevated slab is being tested, the testing must also be completed before any shores have been removed. Any failure to complete the testing in accordance with these requirements constitutes de facto acceptance of the work.

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### WHAT ARE MINIMUM LOCAL FF AND FL NUMBERS?

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On every project the **minimum local areas** are defined to be the floor areas bounded either by the column and half-column lines, or by the construction and control joints, whichever are smaller. A project's minimum local FF and FL numbers (abbreviated as **MLFF** and **MLFL**) are the various FF and FL numbers exhibited by each of these individual minimum local areas. Since these two values define the **minimum usable floor flatness and levelness quality at any location**, they can never represent the profile quality exhibited by any larger

area. Consequently, neither the **MLFF** nor the **MLFL** can ever refer to the profile quality in a single bay or placement.

Every properly drawn F-Number specification must require the installer to deliver a specific set of MLFF and MLFL numbers in each individual minimum local area (see below for limits on the specification of MLFL).

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### WHEN ARE THE MINIMUM LOCAL MLFF AND MLFL NUMBERS MEASURED?

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Normally, the individual **minimum local test sections** are not tested initially. Instead, each placement's aggregate FF and FL numbers are measured first, and if those results are satisfactory, the minimum local tests are waived.

However, if the aggregate FF and FL results for a given test area do indicate the likelihood of a minimum local violation, then all of the suspect minimum local test sections within that test area must be tested individually in accordance with ASTM E 1155M. The large differences between the specified overall and specified minimum local FF and FL values guarantee the statistical validity of this economical two-tiered testing scheme.

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### WHAT DOES AN F-NUMBER SPECIFICATION PROMISE TO THE OWNER?

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Every properly drawn F-Number specification promises two things to the owner:

- That when completed and viewed as a whole, the entire project floor will exhibit OAFF and OAFL numbers that meet or exceed their respective specified values, and
- That no individual minimum local area will exhibit an MLFF or MLFL number lower than their respective specified values.

The first result promised to the owner requires the installer to select a floor construction method that will at least produce on average the required OAFF and OAFL values. The second result promised to the owner requires the installer to select a floor construction

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## WHAT FF AND FL NUMBERS EQUAL THE VARIOUS DIN 18202 GROUP LIMITS?

As noted above, there can be no FF number or FL number equivalents to any “gap under the straightedge” type specification. If straight-edge tests produced the same information as that contained in the FF and FL numbers, then the F-Number System would not be necessary. By making certain assumptions, however, it is possible to approximate a rough correspondence between the two systems:

Group	Permitted flatness deviations [mm] for measurement point distanes [m]						Approximate F-Numbers	
	0,1	1	4	10	≥ 15	OAFF	O AFL	
1	10	15	20	25	30	8	24	
2	5	8	12	15	20	14	40	
3	2	4	10	12	15	31	49	
4	1	3	9	12	15	45	53	

The above OAFF approximations were obtained by first equating twice the maximum gap allowed by DIN 18202 at the mid-point of a 0,6m straightedge to the F-Number System’s  $q_{max}$  estimation in order to compute MLFF. The resulting MLFF value was then divided by 0,6 to obtain its associated OAFF. Similarly, the above approximations for OAFL were obtained first by equating the maximum gap allowed by DIN 18202 at the mid-points of a 6m straightedge to the F-Number System’s  $z_{max}$  estimation in order to compute MLFL – once again dividing the resulting MLFL by 0,6 to obtain the associated OAFL.

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## WHAT IS WRONG WITH THE DIN 18202 STRAIGHT-EDGE METHOD?

DIN 18202 specifies the maximum gaps allowable under freestanding straightedges of various lengths. The distance between contact points is treated as the wavelength, and the gap under the straight-



edge is treated as twice the amplitude. While the method's attempt to control these two critical wave characteristics is praiseworthy, the means employed by the method to accomplish this goal are fatally flawed.

In direct conflict with the Shannon-Nyquist Theorem, the DIN 18202 method subscribes to the false notion that additional useful information about the profile's wave content can somehow be obtained by increasing – rather than decreasing - the sample point spacing. This fundamental error leads directly to the method's requirement that a series of pointless and contradictory gap tests be performed using various straightedges of ever increasing length.

The maximum allowable gaps associated with the infinity of possible wavelengths to be tested are unrealistic. For the shorter wavelengths (<120 cm) the specified maximum gap is too lenient, while for longer wavelengths (> 4 m), the specified maximum gap is too strict. Consequently, if only the shorter waves be tested, a typical "wet screeded" floor (FF30/FL18) might very well pass the DIN 18202, Table 3, Group 3 requirement. If only the longer waves be tested, however, then a much better "laser screeded" floor (FF50/FL30) might just barely pass the very same requirement!

Because DIN 18202 does not explain precisely how to conduct the test (e.g. neither the number of measurements nor the measurement locations are specified), the method is highly susceptible to manipulation. DIN 18202 tests are, in fact, always carried out arbitrarily – a deficiency that routinely leads to much confusion and dispute.

The test is too impractical to employ regularly. Owing to both the slowness and unwieldiness of the method, DIN 18202 specified floors are hardly ever tested during construction. When the test is eventually performed, it is usually in response to the appearance of some obvious problem – like the appearance of puddles or the way the lift trucks are shaking. Months after the floor's installation, the straightedge is finally hauled out to "prove" the legitimacy of the owner's complaint. Unlike meaningful contemporaneous testing and reporting, this "after the fact" testing does nothing to direct the floor's construction towards a successful result.

The method has no statistical validity. Though confronting an infinite sample space (viz. there are an infinity of possible measurement locations), the method provides no statistically valid means for organizing the test space, or for assembling and analyzing the gap data it collects in a scientifically meaningful way. It just employs a primitive



“pass / fail” acceptance criterion and then leaves it up to the user to sort out the consequences.

**DIN 18202 thus provides no logical means for determining equitable remedy.** The method is simply silent regarding exactly what is supposed to happen after a floor “fails” the test. Since all the shortcomings of the procedure rule out any possibility of evolving any scientific means for addressing non-compliance, the method is to all intents useless for project management purposes.

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## WHAT FF AND FL NUMBERS EQUAL THE VARIOUS TR-34 PROPERTY LIMITS?

TR34 limits two distinct floor profile variables, Property II and Property IV. There is a direct relationship between F-Numbers and Property II and IV, since  $q_{max}$  (the profile variable that must be estimated to determine MLFF) is, in fact, the 100% Property II value, and  $z_{max}$  (the profile variable that must be estimated to determine MLFL) is essentially the 100% Property IV value. The OAFF and OAFL values associated with Property II and IV are then obtained from these equivalent MLFF and MLFL values by dividing both by 0,6.

Floor classification	Property II limit		Property IV limit		Equivalent F- Numbers	
	95%	100%	95%	100%	OAFF	OAFL
FM1	2,5	4,0	4,5	7,0	48	75
FM2	3,5	5,5	8,0	12,0	35	44
FM3	5,0	7,5	10,0	15,0	26	35

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## WHAT IS WRONG WITH THE TR-34 METHOD?

TR-34 actually appears to be modeled after ASTM E 1155M. Unfortunately, however, it is missing some of the F-Number System’s most important elements. For example, by limiting the specified tolerances to a few fixed values (viz. FM1, FM2, FM3), the TR-34 method simply lacks the flexibility to support the effective specification and control of a modern floor construction project. Like DIN 18202, TR-34 just employs a primitive pass/fail criterion for gauging the subject floor’s

compliance, and consequently, the **TR-34 method, like DIN 18202, likewise provides no logical means for determining equitable remedy.** The method simply remains silent regarding exactly what is supposed to happen after a floor “fails” the test.

The tolerances associated with the various FM categories are also known to be unrealistic. In many cases, no real floors exist that will marginally satisfy all of the tolerances at once. Indeed, rather than placing reasonable, consistent limits on both the flatness and levelness properties, it is not unusual for one of the tolerances in particular category – that being the one that is relatively the “strictest” in that category – to end up driving the rest of the specification by itself. If that one “strictest” tolerance is marginally satisfied, then all of the other much less stringent tolerances in that same category will be easily satisfied - thus rendering them superfluous.

The TR-34 method also fails to provide the essential protections afforded to both the owner and the installer by the “Overall” and “Local Concepts” found in the F-Number System. Essentially, since every TR-34 tolerance is treated essentially as a minimum local value, all distinctions between “overall delivered value” and “minimum useable local condition” are lost.

For the above reasons, to all intents, the TR-34 method – like DIN 18202 - has proven itself to be essentially useless for project management purposes.

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## **I’VE BEEN MEETING THE SPECIFIED STRAIGHTEDGE TOLERANCES FOR YEARS, SO WHY SHOULD I HAVE ANY PROBLEM MEETING FF-50?**

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**Just because the floor was accepted and paid for doesn’t mean that it actually met the specified tolerance.** The only way to be sure that a tolerance is met is by measuring the result immediately after installation. In all probability, most of the concrete floors placed in the last 40 years would measure somewhere between OAFF-18 and OAFF-35, and OAFL-11 and OAFL-21. The old adage certainly applies here: People do what you inspect, **not** what you expect.

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## HOW CAN I FIND OUT WHAT F-NUMBERS I'VE BEEN PRODUCING?

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**Just hire a testing lab to measure some of your old jobs.** If your local lab doesn't have a D-Meter or F-Meter, you can rent or purchase one and measure your old floors yourself. Then you will know exactly what F-Numbers you have been able to produce under the particular circumstances that were encountered on each project tested.

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## I DON'T NEED FLOORS THAT ARE VERY FLAT, SO WHY SHOULD I WORRY ABOUT F-NUMBERS?

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**Using F-Numbers doesn't mean that floors have to be specified any flatter than is needed.** But without F-Numbers, there is simply no way to measure reliably what floor flatness/levelness was actually produced. For example, typical "wet-screeded" concrete floors measure about OAFF 25 / OAFL 15. While many building owners might be satisfied with this result, others would find many areas on such a floor that they would want "fixed".

**And what happens if no floor tolerances are specified,** and an OAFF-15/OAFL-9 is produced? Most owners are going to be very unhappy with this result. But without clearly defining exactly what is and what is not satisfactory in specifications, the owner of the building has no control whatsoever over what he is buying.

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## WHAT GOOD IS IT TO MEASURE THE F-NUMBERS AFTER THE FLOOR HAS BEEN FINISHED ... ISN'T THAT ALREADY TOO LATE?

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**F-Numbers were not invented as a way to cast blame. When used properly, F-Numbers immediately identify problems and prevent their recurrence.** An F-Number competent contractor has learned which placement and finishing procedures are needed to prevent a significant failure. Remember, the F-Number measurements are

taken as soon as each day's placement will bear foot traffic, and the formal F-Number compliance report is issued before the next slab is placed. With this daily measurement and reporting scheme, problems are quickly identified and eliminated.

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## THAT'S FINE FOR THE SECOND POUR, BUT WHAT DO YOU DO TO ENSURE THAT THE FIRST POUR WILL BE OK?

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**Placing floors to achieve certain F-Numbers is not guesswork.** Billions of square meters of concrete have been placed over the past 30 years using the F-Number System. Flatwork contractors have learned that by using certain placement and finishing techniques, they can routinely achieve certain F-Numbers. Thus, if a job be specified at OAFF-50/OAFL-30, an installer should use the procedures which typically produce those F-Numbers - or to play it safe, methods which are known to produce somewhat higher F-Numbers. **So the keys to meeting F-Number specs are:**

- **Choose the correct placement and finishing procedures to meet the specified F-Numbers,**
- **Measure each day's work as soon as possible, so if there's a problem, it will be identified and corrected before it's repeated.**

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## HOW DOES A NOVICE KNOW WHAT F-NUMBERS TO SPECIFY?

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**There are two ways to select the proper F-Numbers for a given floor usage:**

- The first and the best way is simply to identify a floor in a building that the user is already happy with. The F-Numbers for this floor can then be measured and used to develop the specification for the new floor.

- If that's not practical, you can use the F-Numbers suggested by the Specifier's Guide to F-Numbers and others, which are based on the experience gained from thousands of projects around the world.

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## HOW EXACTLY ARE F-NUMBERS MEASURED?

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**F-Numbers are derived from a statistical analysis of the floor's surface profile measured at 30cm and 3m intervals. The differences between adjacent 30cm slope measurements are used to calculate FF, while the elevation differences between points separated 3m are used to calculate FL.** Basically, measurement lines are laid out on the floor, and point elevation measurements are recorded every foot down the line. Every measurement line must be at least 3,3m long, and a minimum number of 3m elevation difference readings must be collected according to the size of the area being tested. Specific rules for performing F-Number tests are set forth in **ASTM E1155M**. After collection, the elevation readings are used in prescribed equations to calculate the area's estimated F-Numbers. While any device capable of collecting the required point elevation measurements will satisfy the ASTM instrument requirements, the D-Meter and F-Meter are both particularly well suited for the task.

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## HOW LONG DOES IT TAKE TO MEASURE A FLOOR?

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**Using a D-Meter, a competent technician can measure about 900 square meters per hour. With an F-Meter, the measurement speed increases to about 2500 square meters per hour.** Both units calculate the results for screen display instantly. For data listing and graph generation, both units can also quickly download to any device running Excel that is fitted with a USB port. The Daily Report and Charts program provided on the Allen Face Europe website ([www.allenface-europe.com](http://www.allenface-europe.com)) allows the formal report to be prepared in just a few minutes.

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## CAN F-NUMBERS BE MEASURED LESS OFTEN - FOR EXAMPLE, ONLY AT THE END OF THE JOB?

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For many very good reasons, **ACI 117-10 mandates the testing of floor flatness and levelness within the first 72 hours after slab installation.** On most projects, daily testing is best. A significant delay between placement and measurement can allow shrinkage or deflection phenomena (such as curling) to affect the results. One of the principal objectives of timely measurement is to establish clearly whether the Contractor did or did not do his job, so that both the causes and remedies for any problems found can be easily determined.

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## WHO SHOULD DO THE TESTING?

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Given the large amount of money that is usually at stake, every specification should require that a Certified F-Number Technician to be employed to perform all contract compliance tests. Every three months Allen Face Europe conducts a day-long F-Number technician class in Budapest, Hungary (on the 2<sup>nd</sup> Saturday of March, June, September, and December). These classes cover every critical aspect of F-Number theory, specification, measurement, and defect resolution. Most of the disputes that are routinely encountered in association with the F-Number System – or with floor tolerances in general - can be avoided simply by having a properly trained technician on-site from the outset. For further details regarding F-Number Training and Consultation contact Noemi Nagy (+36 70 316 0745, [noemi.nagy@allenface.com](mailto:noemi.nagy@allenface.com))

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## WHAT IF THE FLOOR DOESN'T MEET THE SPECIFIED F-NUMBERS?

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**This is a question that must be answered explicitly not only before the floor installation begins, but before the floor installation contract is even signed!** To protect everyone's interests, the specification must set forth in detail all of the remedies that will be required in the event of negative result. Otherwise, since full payment typically trails satisfactory completion by many months, an unreason-

able owner can easily leverage the flatwork contractor into providing an unreasonable remedy.

Because there are two sets of F-Numbers included in every specification (i.e. the “overall” and “minimum local” numbers), there are two ways to fail to meet the tolerances. Furthermore, because these two sets of F-Numbers are not equally important to the owner’s satisfaction, the appropriate remedy to be applied will change with the type of defect encountered.

As explained above, since the OAFF and OAFL numbers define the average quality to be delivered over the entire project, liquidated damages - not physical correction - are the logical means of remedy. In contrast, since the MLFF and MLFL numbers define the minimum useable result, physical alteration of the offending minimum local areas is the logical remedy.

**The sample F-Number specification given at <http://www.allenface.com/sample> provides an ideal example of such remedy-specific contract language.** All project participants are strongly advised to compare and contrast their project specifications with this sample, and to revise their specifications when a conflict or deficiency is identified.

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## SO EXACTLY WHAT DOES HAPPEN IF THE SPECIFIED OVERALL F-NUMBERS ARE NOT ACHIEVED?

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**As long as both the specified MLFF and MLFL values are satisfied, no physical corrections are required.** The contractor simply rebates to the owner an amount calculated using a liquidated damages formula given in the specification.

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## HOW IS THE AREA THAT FAILS TO MEET THE SPECIFIED OVERALL F-NUMBERS CALCULATED?

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**The Daily FF/FL Report given at <http://www.allenface.com/projectmgmt.html> automatically provides running tallies of the aggregate defective, equivalent, and superior areas in place.** This keeps everyone informed of the prospective liquidated damages amount at all times.

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## ... AND IF THE SPECIFIED MINIMUM LOCAL F-NUMBERS ARE NOT ACHIEVED?

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Since the specified MLFF and MLFL values equate, by definition, to the minimum useable floor quality, full physical correction (e.g. by grinding, by depression and re-topping, or by removal and replacement) of each defective minimum local section is required.

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## IF I WANT TO USE THE F-NUMBER SYSTEM, DO I HAVE TO BUY A D-METER OR F-METER?

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**No. While these instruments do offer the simplest and least expensive way to monitor projects specified using F-Numbers**, because many labs have the necessary equipment, and the units can be rented easily, owning one is not necessary.

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## CAN ANYONE OPERATE A D-METER OR F-METER?

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**It typically takes less than 30 minutes to learn how to run one of these instruments.**

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## HOW CAN I IMPROVE THE F-NUMBER RESULTS?

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While many factors can influence the F-Numbers that are produced, **there is still a very simple principal to follow when trying to achieve higher numbers.** If the floor installation process be divided into the two broad phases of “placement” and “finishing” - where “placement” includes all the steps (including edge forming) that are performed through strike-off, and “finishing” includes everything that is done to the slab thereafter, then **FF may be considered almost a pure measure of “finishing quality”, and FL may be considered almost a pure measure of “placement quality”.**

Therefore, trying to improve FF significantly by erecting better edge forms or by switching from wet screed to Screed Rail, or FL Screed, or Laser Screed strike-off will not achieve much (other than to improve

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## WHAT IS A SUPERFLAT FLOOR?

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your FL numbers). Likewise, trying to improve FL significantly by changing from float shoes to pans or by adding a bump cutting step after the first float pass will not achieve much (other than to improve your FF numbers).

On defined traffic floors, **“Superflat” = Fmin-100**. The Edward W. Face Company of Norfolk, Virginia, USA coined the term superflat in the late 1970’s to describe the wheel track flatness/levelness required to support the full-speed operation of Very Narrow Aisle (VNA) lift trucks. The various construction methods required to strike-off and finish such floors have changed considerably over the past three decades, and a number of significant economies are now available. The science still remains in flux, however, and the owner’s employment of an expert concrete floor consultant is strongly advised.

On random traffic floors, **“Superflat”** equates to the approximate Fmin-100 equivalent of **OAFF-140/OAFL-100**. Such extraordinarily “tight” tolerances are rarely required (if ever), however, and would only be specified in the most extraordinary circumstances.

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## ISN’T A RANDOM TRAFFIC SUPERFLAT FLOOR THE SAME THING AS A DEFINED TRAFFIC SUPERFLAT FLOOR?

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**No.** A defined traffic floor supports traffic that is mechanically (or electro-mechanically) confined to transit the floor along fixed paths. Consequently, the floor can be measured (e.g. along the fixed wheel tracks) precisely as it will be seen by the future traffic at all locations. Originally, such vehicle simulation measurements were made using the Face Floor Profileograph by matching the instrument’s wheel configuration to that of the actual lift truck to be used. The technician would then roll the Profileograph down the future wheel tracks in each aisle and thereby record the **relative side-to-side and front-to-back motions imposed upon the instrument by the floor**. Since the lift trucks’ suspensions are fitted neither with springs nor shock absorb-

ers, if the damping provided by the tire treads be ignored, then the floor may be viewed as the moving trucks' forcing function. Controlling the floor thus places absolute and direct control over the angular tilts, velocities, and accelerations to be experienced by the trucks around both their roll and pitch axes.

In contrast, the FF and FL numbers used to control the local flatness and levelness of random traffic floors only gauge the floor statistically, and consequently are poorly suited to the task of identifying exactly where and by how much a wheel track profile must be altered to reduce a vehicle's composite motions.

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## HOW IS A DEFINED TRAFFIC SUPERFLAT FLOOR MEASURED?

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Until recently (viz. 2005), the Face Floor Profileograph (or one of the several derivatives now being offered by former Face employees) has been the only instrument capable of providing the necessary composite wheel track readings. In 2005, however, Allen Face modified the D-Meter's and F-Meter's software to perform the requisite calculations, and much more importantly, **to calculate the optimum (i.e. minimum) spot grinding depths required to bring the wheel track combination simultaneously into full compliance with all six critical aspects of the Fmin tolerance** [i.e. degree of roll, roll rate, degree of pitch (traveling forwards), pitch rate (traveling forwards), degree of pitch (traveling backwards), and pitch rate (traveling backwards)].

Prior to the invention of this sophisticated software, the six dimensional optimization problem to be solved was far beyond human visualization. As a consequence, corrective wheel track grinding has characteristically been an expensive and highly inefficient "tail chasing" exercise wherein the correction of one type of defect (e.g. a transverse levelness defect) often immediately results in the creation a new defect of some other type (viz. a longitudinal flatness defect).

Since the D-Meter's and F-Meter's grinding optimization software has been shown **to reduce corrective grinding costs by more than 80%**, these units have become the instruments of choice for testing Fmin tolerances. And since the F-Meter can collect the data about 10 times faster than the D-Meter (viz. 40m/min vs. 4m/min), it is by far the preferred instrument.

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## HOW MUCH EXTRA DOES A SUPERFLAT FLOOR COST?

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**Today, sometimes little or nothing.** In late 2011 Allen Face designed and oversaw the installation of a 60000m<sup>2</sup> Fmin-60 specified floor that was placed by direct discharge and struck-off using a Somero 240 Laser-Screed. The warehouse comprised one hundred (100) aisles, each measuring 132m in length. In total, the warehouse contained some 40km of wheel tracks.

The floor was placed in 3000m<sup>2</sup> sections and was tested each day immediately following final finishing using a D-Meter. The entire floor installation was completed in less than 4 weeks, and not a single foot of corrective wheel track grinding was required. Even when analyzed against Fmin-100, less than 6% of the total wheel track was identified as defective. Similar results have also been obtained recently on two projects in Puerto Rico.

Historically, the production of close tolerance floors has required that the concrete be placed narrow strips between extremely accurate edge forms. Placement rates of 600m<sup>2</sup> to 900m<sup>2</sup> per day have been typical, and the associated construction premiums have exceeded 7 Euros per square meter. Many projects - especially those executed in areas where the labor is unskilled - still require the use of such techniques and the payment of such premiums..

Significantly, by using AF-E's grinding optimization software, **the additional cost incurred on wide-placement projects by grinding the wheel tracks into compliance with the Fmin-100 tolerance is now at or below the additional cost incurred in trying to meet the Fmin-100 tolerance by strip pouring.** Again, in order to realize such significant economies, the owner is strongly advised to retain the services of an expert defined traffic concrete floor consultant.

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## I CAN UNDERSTAND HOW GRINDING CAN BE USED TO CORRECT HIGH SPOTS ON SUPERFLAT FLOORS, BUT HOW CAN GRINDING FIX LOW SPOTS?

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From the lift truck's point of view **there are no low spots**. Since a low spot on one side is equivalent to a high spot on the other side, by addressing the relatively higher spot, grinding can always be used both to bring the wheel tracks into vertical correlation and to smooth out any localized composite curvatures.

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## CAN A FLOOR BE SUPERFLAT EVEN IF THE AISLE IS DESIGNED TO SLOPE LENGTHWISE?

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**Yes.** The Fmin levelness calculations can easily be adjusted to compensate for any intentional longitudinal slope. It's important to remember that the floor profile characteristics that are critical to efficient, full-speed vehicle operation are the local flatness/levelness characteristics that dictate how easily the truck moves from one location to another. In most cases, the truck really doesn't care whether one end of the aisle is higher or lower than the other. It only cares about the number and severity of the bumps and dips it will encounter as it travels from one end of the aisle to the other.

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## HOW ABOUT INTENTIONAL SLOPES ACROSS THE AISLES?

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**Yes again.** The Fmin levelness calculations can also be adjusted easily to compensate for any intentional transverse slope. Extensive tests on narrow aisle lift trucks indicate that intentional lateral tilts of up to 5 degrees can be accommodated, as **long as the floor is kept flat**. Allen Face has monitored the installation of the superflat floors in several hazardous liquid storage warehouses where the aisles had to be tilted laterally in order to achieve the required drainage in the event of a spill. In one case, the whole building was designed to slope

about 2% from side to side. Again, these are the kinds of issues that are best handled by an expert.

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## **CAN'T I SAVE MONEY BY MAKING MY FLOOR SUPER-FLAT ONLY IN THE TRAVEL PATHS AND NOT UNDER THE RACKS?**

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Actually, because the Fmin compliance tests are only performed in the wheel tracks, this is precisely what is being done. It is a fact that the floor flatness/levelness tolerances needed to support rack erection are much less stringent than those required to support vehicle operations. Consequently, since practicality severely limits the flatwork contractor's ability to localize his delivered quality, the extraordinary results that are also routinely produced under the racks are essentially obtained "for free".

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## **SOMEDAY I MIGHT WANT TO RUN MY RACKS THE OTHER WAY. CAN A FLOOR BE BUILT SO THAT IT'S SUPERFLAT IN ALL DIRECTIONS?**

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The wide-placement floors constructed using Laser-Screeds (see above) come the closest to achieving omni-directional superflatness. Fortunately, since the location of the loading docks is invariably fixed by the building's exterior arrangement, and the aisle locations are always dictated by the column spacing, the chances that the racks will ever be moved are extremely remote. Even if that were to happen, as discussed above, the cost associated with grinding the new wheel tracks into the required Fmin number will not be great.

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## HOW CAN I MAKE AN EXISTING CONVENTIONAL FLOOR SUPERFLAT?

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There are four alternatives:

- Install a superflat topping throughout the entire building
- Install a superflat topping throughout the entire rack area (and ramp down to the surrounding original floor)
- Install a superflat topping only in the aisles and turn-arounds (install pallet supports under the racks and ramp down to the surrounding original floor)
- Use the F-Meter or D-Meter and its associated grinding optimization software to grind the wheel tracks into tolerance

And one mandatory item:

- Hire an expert.

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## HOW DO I GET MORE INFORMATION ON F-NUMBERS AND FLOOR FLATNESS/LEVELNESS?

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Technical literature on floor flatness/levelness is available free of charge from Allen Face Europe. Please contact Noemi Nagy (+36 70 316 0745, [noemi.nagy@allenface.com](mailto:noemi.nagy@allenface.com)). The company's website - <http://www.allenface-europe.com> - is also an excellent resource.